Journal of Agricultural Science; Vol. 4, No. 10; 2012
ISSN 1916-9752 E-ISSN 1916-9760
Published by Canadian Center of Science and Education

Heterosis and Combining Ability in CMS Based Hybrid Chilli (*Capsicum annuum* L.)

B. V. Tembhurne[1] & S. K. Rao[1,2]

[1] Department of Plant Breeding and Genetics, Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur (JNKVV), Madhya Pradesh, India

[2] Director Farms, Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur, Madhya Pradesh, India

Correspondence: B. V. Tembhurne, College of Agriculture, University of Agricultural Sciences, Raichur 584 101, Karnataka, India. E-mail: bvtembhurne@gmail.com

Received: May 30, 2012 Accepted: June 16, 2012 Online Published: August 24, 2012

doi:10.5539/jas.v4n10p89 URL: http://dx.doi.org/10.5539/jas.v4n10p89

Abstract

Field experiments were conducted during *kharif* 2009-2010 to identify the most heterotic CMS based hybrids in chilli. The heterosis for dry fruit yield and yield components of 51 F_1 hybrids were derived from crosses between three females (line) and seventeen males (tester) crossed in line x tester fashion. The cross ACA1/LCA334 exhibited significant heterosis over mid parent 493.44% as well as better parent 402.78%. The F_1 hybrid JNA1/BVC-37 registered significant standard heterosis (48.47%) for dry fruit weight plant^{-1}. The highly significant gca effect revealed that LCA960, BVC37, LCA334, PantC1 and JNA1 were good general combiner among the male and female, respectively. The hybrid JNA1/BVC37 gave the highest yield for dry as well as green fruits along with highly significant sca effects.

Keywords: heterosis, heterobeltiosis, *Capsicum annuum*, chilli, combining ability

1. Introduction

India is the largest producer of chilli in the world owing to the availability of improved varieties. The role of hybrid seed in India is limited and the production of hybrid cultivars can be successful only if adequate quantities of hybrid seeds are produced at reasonably low cost. The hybrid seed production in chilli requires tedious process of emasculation and pollination. Chilli flowers are delicate in nature, resulting in flower drop or poor fruit set after emasculation. Moreover hand pollination increases the cost of hybrid seed production due to high labour cost. In the recent years hybrid cultivars have become popular and many farmers are producing hybrid seeds of hot pepper based on nuclear male sterility (Dash et al., 2001). Development of male sterility system is the only alternative to reduce the cost of seed production as it is being practiced in other vegetables. The male sterile (S-) cytoplasm has so far been most commonly utilized for commercial hybrid development in South Korea, China and India (Kim & Kim, 2005; Kumar et al., 2007). However, rapid transfer of male sterile cytoplasm (nuclear diversification of CMS) in Indian genotypes has been a handicap due to the limited availability of maintainer allele (*rf*) in chilli genotypes (Kumar et al., 2007) leading to restriction in the choice of the parents (Zhang, 2000). A major fertility restorer locus (*Rf*) is known to restore fertility of this S-cytoplasm, but it is influenced by temperature, quantitative trait loci (QTLs)/modifiers (Wang et al., 2004) and conditioned by an additional partial restoration (*pr*) locus (Lee et al., 2008a). This *pr* locus is suspected to be either tightly linked to *Rf* locus or is third allele of *Rf* locus (Lee et al., 2008b). In *Capsicum*, very few stable nuclear-cytoplasmic male sterile (CMS) lines are known because male sterility expressions in CMS lines have been found to be temperature sensitive (Shifriss, 1997). Temperature alteration may induce a degree of variation in male sterility, ranging from complete to partial. Selfing as well as crossing of the male sterile individuals can be achieved through temperature manipulation. Therefore, breeders must use restorer as well as maintainer lines for various environments to secure a completely sterile female parent, but fully fertile hybrid.

One important aim of hybrid breeding is to exploit the heterosis effect appearing in the F_1. In development of high yielding varieties and hybrids of crop plants, the breeder often faces the problem of selecting parents and crosses. Common approach of selecting parents on the basis of *per se* always does not lead to fruitful results (Allard, 1960). The selection of parents has thus to be based on complete genetic information and knowledge of combining ability of potential parents.

Combining ability analysis in this respect is considered to be an efficient technique not only for selection of desirable parents and crosses but also characterizes nature and magnitude of gene action in the expression of a trait. Knowledge about the type and amount of genetic effects is required for an efficient use of genetic variability of crops. The concept of good combining ability refers to the potential of a parental form for producing superior offspring by crossing with another parent for the breeding process. Information and exact study of combining ability can be useful in regard to selection of breeding methods and selection of lines for hybrid combination. Due to the numerous theoretical and practical advantages of this method, in recent years the choice of parental forms on the basis of combining ability has been extended.

Keeping in a view the present investigation was undertaken to identify the most heterotic male sterility based hybrids and generate information on general and specific combining ability effects for selection of parents (male sterile and restorer lines) for promising hybrid combinations.

2. Materials and Methods

2.1 Plant Material

The experimental material comprised of fifty one F_1 hybrids developed from three females (CMS lines) viz., JNA1, ACA1 and ACA2 including seventeen male lines viz., SKS, PantC-1, G-4, K1-4C, 9608U, BVC-1, GUK-1, GUK-2, GUK-2-1, LCA334, LCA960, KDC-1-1, P. Jwala, KA-2, K1-4D, PSBR and BVC-37. Seventy one entries including twenty parents and their 51 F_1 hybrids were evaluated in a Completely Randomized Block Design (CRBD) with two replications during *kharif* season 2009-2010 at JNKVV, Jabalpur (Madhya Pradesh). The plot size for each accession was 6m x 1.2m where in both row-to-row and plant-to-plant spacing was 60 cm x 60 cm. The crop was raised as per the standard package of practice. The experiment was repeated thrice by transplanting the seedlings at the interval of twenty days. Timely management practices were followed to grow a good crop. Five plants were randomly selected/plot for recording data on days to first flower initiation, days to first fruit ripening, days to first harvest, number of pickings, number of fruits plant^{-1} number of primary branches and plant height (cm), where as ten fruits were selected (two fruits from each randomly selected plant) for fresh weight fruit^{-1} (g), dry weight fruit^{-1} (g), fruit length (cm), fruit diameter (cm), pedicel length (cm), petiole length (cm), number of seeds fruit^{-1} and 1000 seed weight (g). For days to 50% flowering data was recorded on plot basis.

2.2 Statistical Analysis

The estimates of heterosis and combining ability were computed on mean performance of hybrids and their parents over two replications for each date of transplanting. Data on three transplanting dates were subjected to analysis for heterosis (Turner, 1953; Fonseca & Patterson, 1968) and Line x Tester (Kempthorne, 1957) for combining ability analysis as per the standard procedure.

2.2.1 Estimates of Heterosis

Relative hybrid performance (in per cent) in comparison with the mean of both parents (mid-parent heterosis, MPH), better parent, BPH and standard heterosis, SH were calculated as follows respectively:

MPH = (F1 - MP)/MP) x 100, Where, F1 = mean performance of hybrid, MP = average performance of both parents.

BPH=(F1 - BP)/BP) x 100, Where, F1 = mean performance of hybrid, BP = mean performance of better parents.

SH = (F1 - SC)/SC) x 100, Where, F1 = mean performance of hybrid, SC = mean performance of standard check (Parvez, 2006).

3. Results and Discussion

3.1 Analysis of Variance

The estimates of mean square due to genotypes and parents were significant for all the traits (Table 1) indicating the presence of large amount of diversity among the genotypes and respective group of the material studied. Mean squares due to line, testers, and line x testers were also significant for most of the traits revealed the differences among females and males. The comparison of parents vs crosses was significant for all the traits suggesting presence of hybrid vigour for all the characters.

Table 1. Analysis of variance for eighteen yield related traits in chilli

Source	D.F.	DFI	DFF	DFR	DFH	NOP	NFP	FFW	DFW	FL	FD	PL	PTL	NPB	PH	NS	SW	FFWP	DFWP
Transplanting dates	02	3113.85**	3363.96**	878.79**	787.35**	0.43**	69979.48**	5.99**	0.87**	34.99**	0.45**	15.76**	1.37**	13.68**	902.63**	1358.17**	16.76**	1.72**	0.11**
Genotypes	70	26.40**	29.55**	47.61**	54.21**	0.12**	46710.25**	6.67**	0.30**	23.49**	0.24**	1.58**	0.32**	2.31**	232.34**	1196.69**	3.16**	0.63**	0.04**
Parents	19	20.29**	20.35*	39.02**	44.49**	0.26**	18797.70**	14.45**	0.58**	40.28*8	0.38**	2.87**	0.14**	1.30**	369.31**	946.17**	5.66**	0.48**	0.03**
Lines	16	21.02**	22.41	24.99**	32.07**	0.15**	21044.68**	14.12**	0.62**	41.04**	0.44**	3.01**	0.11**	1.29**	402.51**	858.45**	6.65**	0.46*8	0.03**
Testers	02	2.33	2.86	81.86**	40.53**	0.00	3337.33**	0.50**	0.07*8	6.88**	0.03**	0.05*8	0.06**	1.00**	158.11**	588.00**	0.19**	0.05*8	0.00**
Line vs Testers	01	44.50*	22.43	177.75**	251.06**	2.56**	13766.86**	47.68**	0.93**	94.98**	0.00	6.37**	0.84**	2.07**	260.60**	3066.00**	0.72**	1.79**	0.11**
Parent vs Crosses	01	864.27**	101.42**	955.43**	670.61**	0.68**	1164227.62**	74.86**	0.11**	1.37**	4.64**	7.35**	0.65**	22.41**	4.06	505.62**	6.73**	7.77**	0.49**
Crosses	50	11.97	13.36	32.72**	45.58**	0.05	34966.67**	2.35**	0.20**	17.55**	0.11**	0.97**	0.38**	2.29**	184.86**	1305.71**	2.13**	0.54**	0.03**
Error	140	10.61	10.80	0.89	0.57	0.03	207.79	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.57	3.95	0.00	0.00	0.00

*, **Significant at p = 0.05 and 0.01, respectively.

DFI = Days to first flower initiation, DFF = Days to fifty per cent flowering, DFR = Days to first fruit ripening, DFH = Days to first harvest, NOP = Number of pickings, NFP = Number of fruits plant^{-1}, FFW = Fresh fruit weight fruit^{-1} (g), DFW = Dry fruit weight fruit^{-1} (g), FL = Fruit length (cm), FD = Fruit diameter (cm), PL = Pedicel length (cm), PTL = Petiole length (cm), NPB = Number of primary branches, PH = Plant height (cm), NS = Number of seeds fruit^{-1}, TSW = 1000 seed weight (g), FFWP = Fresh fruit weight plant^{-1} (kg), DFWP = Dry fruit weight plant^{-1} (kg).

3.2 Mean Performance of Parents and Hybrids

The range for mean performance and various heterotic effects as well as promising crosses identified on the basis of these two parameters are narrated in Table 2. The maximum range of mean performance was observed for number of fruits plant^{-1} for both, parents (71.67 - 388.33) and hybrids (162.33 – 565.17) along with high heterotic effects over mid parent (21.75 – 658.29), better parent (-1.8 – 651.37) and standard check (43.02 – 397.94). Genotypes BVC-37, BVC-1, GUK2-1, LCA960 and K1-4D registered as better parents based on per se performance for dry fruit weight plant^{-1}. KA-2 exhibited better parent for days to first flower initiation and days to fifty per cent flowering, JNA1 for days to first fruit ripening and days to first harvest, PSBR, K1-4D, KA-2, KDSC1-1 and LCA960 for number of pickings, PantC1 for number of fruits plant^{-1}, LCA960 for fresh weight fruit^{-1}, dry weight fruit^{-1}, number of seeds fruit^{-1} and 1000 seed weight , SKS for fruit length, GUK2-1 for fruit diameter, G-1 for pedicel length, BVC-37 for petiole length, fresh fruit weight plant^{-1} and dry fruit weight plant^{-1}, 9608U for number of primary branches plant^{-1}.

Table 2. Five bests parents for eighteen characters in chilli

Characters	Range					Better parents (Based on per se performance)
	Per se performance		Heterosis			
	Parents	Crosses	MP	BP	SH	
Days to first flower initiation	33.17-44.33	32.00-41.83	-18.22 to 5.24	-24.06 to 0.40	1.59 to 32.80	KA-2 (33.17), K1-4C (35.50), ACA1 (36.17), ACA2 (37.50), PantC1 (37.83)
Days to fifty per cent flowering	37.00-48.33	35.33-45.67	-18.08 to 4.18	-23.45 to 0.74	-0.93 to 28.04	KA-2 (37.00),K1-4C (39.17), GUK2-1 (40.33), ACA1 (40.50), PantC1 (41.00)
Days to first fruit ripening	93.33-105.5	82.67-94.33	-13.69 to 0.74	-21.33 to 0.89	0.81 to 15.04	JNA1 (85.83), ACA1 (93.00), PSBR (93.33), K1-4D (93.50), KDC-1 (94.33)
Days to first harvest	114.17-128.67	105.0-117.67	-11.53 to 0.65	-18.39 to 1.02	-0.49 to 15.93	JNA1 (108.33), ACA1 (113.33), K1-4D (114.17), PSBR (114.33), GUK-2 (115.50)
Number of pickings	2.33-3.00	2.33-3.17	0.00 to 35.71	-5.88 to 35.71	-22.22 to 5.56	PSBR (3.00), K1-4D (3.00), KA-2 (3.00), KDSC1-1 (3.00), LCA 960 (3.00)
Number of fruits plant^{-1}	71.67-388.33	162.33-565.17	21.75 to 658.29	-1.8 to 651.37	43.02 to 397.94	PantC1 (388-33), PSBR (286.33), GUK-2-1 (243.50), BVC-37 (193), 9608U (144.67)
Fresh fruit weight fruit^{-1}(g)	1.59-8.20	1.81-4.91	-54.47 to 85.26	-69.17 to 69.05	-83.33 to -54.12	LCA960 (8.20), BVC-1 (8.00), K1-4D (7.97), BVC-37 (7.53), KDC1-1 (6.13)
Dry fruit weight fruit^{-1}(g)	0.48-1.97	0.41-1.50	-1.09 to 84.38	-62.51 to 70.94	-84.81 to -44.15	LCA960 (1.97), BVC-37 (1.92), BVC-1 (1.63), SKS (1.10), GUK-2-1 (0.98)
Fruit length (cm)	6.10-20.43	4.85-17.52	-25.88 to 86.13	-51.25 to 66.37	-67.39 to 17.72	SKS (20.43), BVC-37 (13.80), K1-4D (12.36), BVC-1 (12.26), GUK-1 (12.06)
Fruit diameter (cm)	0.93-2.24	0.77-1.96	-50.69 to 19.59	-54.05 to -1.42	-49.51 to 28.74	GUK2-1 (2.24), BVC-37 (1.99), LCA960 (1.99), K1-4C (1.64), KDC-1-1 (1.59)
Pedicel length (cm)	2.85-6.96	2.53-4.91	-38.99 to 52.80	-54.69 to 46.72	-48.68 to -0.30	G-4 (6.90), GUK-2 (5.20), SKS (5.00), KDC-1-1 (4.65), BVC-37 (4.54)
Petiole length (cm)	1.36-2.06	1.10-2.63	-32.74 to 59.98	-37.47 to 31.77	-29.27 to 68.80	BVC-37 (2.06), GUK-1 (2.05), P.Jwala (1.95), KA-2 (1.93), GUK-2 (1.41)
Number of primary branches	3.79-5.79	3.79-7.89	-20.87 to 83.88	-34.53 to 79.12	-5.01 to 97.70	9608U (5.79), PantC1 (5.79), BVC-37 (5.29), K1-4D (4.79), KA-2 (4.79).
Plant height (cm)	41.83-83.83	41.83-81.17	-30.85 to 48.31	-37.41 to 44.48	-31.98 to 31.98	SKS (83.83), BVC-37 (81.83), PSBR (76.17), K1-4D (70.50), LCA960 (68.50)
Number of seeds fruit^{-1}	57.50-120.33	32.83-124.50	-54.41 to 52.92	-68.98 to 40.68	-91.11 to -20.78	LCA960 (120.33), K1-4C (105.83), BVC-1 (101.83), K1-4D (95.00), PSBR (92.83)
1000 seed weight (g)	3.24-9.44	3.36-7.68	-36.05 to 69.38	-45.65 to 60.88	-38.90 to 39.62	LCA960 (9.44), BVC-1 (8.25), GUK-2 (5.53), BVC-37 (5.46), GUK-1 (5.38)
Fresh fruit weight plant^{-1} (kg)	0.24-1.81	0.57-2.27	-1.15 to 495.88	-42.79 to 409.86	-63.11 to 47.88	BVC-37 (1.81), BVC-1 (1.39), GUK2-1 (1.17), LCA960 (1.12), K1-4D (0.90)
Dry fruit weight plant^{-1} (kg)	0.06-0.45	0.14-0.57	-0.92 to 493.44	-42.79 to 402.78	-62.88 to 48.47	BVC-37 (0.45), BVC-1 (0.35), GUK2-1 (0.30), LCA960 (0.28), K1-4D (0.22)

3.3 Heterotic Effects of Crosses

Most heterotic crosses are presented in Table 3 revealed that none of the hybrids showed desirable standard heterosis for days to first flower initiation, days to first fruit ripening, fresh weight fruit^{-1}, dry weight fruit^{-1}, pedicel length and number of seeds fruit^{-1}. However, one hybrid each for days to fifty per cent flowering and days to first harvest registered desirable standard heterosis. While 36 crosses for number of pickings, all 51 for number of fruits plant^{-1} and number of primary branches, 2 for fruit length, 1 for fruit diameter, 40 for petiole length, 23 for plant height, 26 for 1000 seed weight and 12 each for fresh fruit weight plant^{-1} and dry fruit weight plant^{-1} exhibited desirable standard heterosis. For fruit length and fruit diameter, most of the crosses were not consistent for their various heterotic effects. These findings are concordance with Joshi et al. (1995), Patel et al. (1997) and Patel et al. (2001).

Table 3. Most heterotic crosses for eighteen characters in chilli for dry fruit yield

Characters	No. of hybrids having significant heterotic effects over SH		Best hybrids based on		
	+Ve	-Ve	MP	BP	SH
Days to first flower initiation	51	0	JNA1/G-4	ACA1/BVC-37	ACA1/GUK2-1
Days to fifty per cent flowering	50	1	ACA2/BVC-37	ACA2/BVC-37	ACA1/GUK2-1
Days to first fruit ripening	51	0	ACA2/LCA334	JNA1/SKS	JNA1/PantC1
Days to first harvest	50	1	JNA1/PantC1	JNA1/SKS	JNA1/PantC1
Number of pickings	36	15	JNB1/BVC-37	JNB1/BVC-37	JNB1/BVC-37
Number of fruits plant^{-1}	51	0	ACA1/LCA334	ACA1/LCA334	ACA12/PantC1
Fresh fruit weight fruit^{-1} (g)	0	51	JNA1/KA2	JNA1/PantC1	JNA1/LCA960
Dry fruit weight fruit^{-1} (g)	0	51	JNA1/GUK2-1	JNA1/PantC1	JNA1/GUK2-1
Fruit length (cm)	2	49	JNA1/GUK2-1	JNA1/GUK2-1	JNA1/SKS
Fruit diameter (cm)	1	50	JNA1/LCA960	JNA1/LCA960	JNA1/LCA960
Pedicel length (cm)	0	51	JNA1/LCA334	JNA1/LCA334	JNA1/GUK2-1
Petiole length (cm)	40	11	ACA2/GUK2-1	ACA2/K1-4C	ACA2/SKS
Number of primary branches	51	0	ACA1/LCA334	ACA2/K1-4C	ACA1/LCA334
Plant height (cm)	23	28	ACA1/LCA334	ACA1/LCA334	JNA1/SKS
Number of seeds fruit^{-1}	0	51	JNA1/BVC-37	JNA1/BVC-37	JNA1/BVC-37
1000 seed weight (g)	26	25	ACA1/9608U	ACA1/9608U	ACA1/GUK2
Fresh fruit weight plant^{-1} (kg)	12	39	ACA1/LCA334	ACA1/LCA334	JNA1/BVC-37
Dry fruit weight plant^{-1} (kg)	12	39	ACA1/LCA334	ACA1/LCA334	JNA1/BVC-37

A perusal of the top heterotic crosses revealed that none of the cross was consistent for all the traits. Among the 51 F_1 hybrids studied 8 crosses viz., JNA1/BVC-37 (48.47%), JNA1/PantC1 (25.76%), JNA1/LCA334 (25.33%), JNA1/LCA960 (24.02%), JNA1/PSBR (22.77%), JNA1/GUK-2-1(16.59%), ACA2/LCA960 (13.10%), ACA1/LCA960 (6.99%) showed significant positive heterosis for dry fruit weight plant^{-1} over standard check VNR 332 (Table 4). However, other thirty nine crosses registered negative standard heterosis and remnant four crosses recorded non significant positive standard heterosis.

Table 4. Heterosis for dry and green fruit yield plant^{-1} for 8 best hybrids in chilli

F1 Crosses	Heterosis over parents/check							
	Dry fruit yield				Green fruit yield			
	Mean	Mid parent	Better parent	VNR332 (check)	Mean	Mid parent	Better parent	VNR332 (check)
JNA1/BVC-37	0.57	104.82**	25.46**	48.47**	2.27	103.44**	25.37**	47.88**
JNA1/PantC-1	0.48	229.14**	152.63**	25.76**	1.92	224.68**	151.86**	25.24**
JNA1/LCA334	0.48	491.75**	370.49**	25.33**	1.91	482.74**	355.56**	24.92**
JNA1/LCA960	0.47	148.03**	69.05**	24.02**	1.90	147.02**	69.90**	24.05**
JNA1/PSBR	0.47	252.20**	185.71**	22.27**	1.88	249.92**	187.72**	22.42**
JNA1/GUK-2-1	0.44	124.37**	50.85**	16.59**	1.78	123.43**	51.70**	16.21**
ACA2/LCA960	0.43	133.33**	54.17**	13.10**	1.73	133.33**	54.40**	12.73**
ACA1/LCA960	0.41	153.89	45.83**	06.99*	1.63	153.37**	45.75**	06.42*

*P = 0.05, **P = 0.01

3.4 GCA and SCA Effects

The gca effect (Table 5) revealed that LCA960, BVC-37, LCA334, PantC1 and JNA1 were good general combiner among the male and female, respectively. Highly significant gca effect recorded by SKS, G-4, PSBR and ACA1 for days to first flower initiation, SKS, G-4, PSBR and ACA1 for days to fifty per cent flowering, JNA1 for days to first harvest, LCA334, LCA960, PSBR, BVC-37 and JNA1 for number of pickings, SKS, BVC-37, GUK-1, GUK-2, LCA960, KDC-1-1, KA-2, K1-4D, BVC-37 and JNA1 for fresh weight fruit^{-1}, SKS, 9608U, BVC-1, GUK-1, GUK-2-1, KDC-1-1, BVC-37 and JNA1 for dry weight fruit^{-1}, SKS, K1-4C, BVC-1, KDC-1-1, K1-4D, BVC-37 and JNA1 for fruit length, 9608U, BVC-1, GUK-2-1, LCA960, K1-4D, BVC-37 and JNA1 for fruit diameter, PantC-1, K1-4C, 9608U, GUK-2-1, LCA334, P.JWALA, PSBR, BVC-37 and JNA1 for pedicel length, SKS, G4, K1-4C, GUK-4, GUK-2, GUK-2-1, KDC1-1, K1-4D, BVC-37, and ACA1 for petiole length, SKS, K1-4C, GUK-1, GUK-2, LCA334, KDC1-1, BVC-37 and JNA1 for number of primary branches, BVC-37 and JNA1 for number of seeds fruit^{-1}, SKS, PantC-1, G-4, 9608U, BVC-1, GUK-1, GUK-2, K1-4D, BVC-37, ACA1, and ACA2 for 1000 seed weight.

Table 5. Estimates of gca effects of parents for different traits in chilli

Parents	Characters																		
Tester	DFI	DFF	DFR	DFH	NOP	NFP	FFW	DFW	FL	FD	PL	PTL	NPB	PH	NS	SW	FFWP	DFWP	NPY
SKS	646**	646**	-145**	-193**	-004**	-631**	016**	007**	389**	-005**	-014**	012**	007**	3873	056	047**	005**	0013**	011**
PantC-1	046	0461	-145**	-293**	-0039**	17535	-048**	-002**	-132**	-008**	016**	-038**	-046**	-046**	-844**	011**	031**	008**	070**
G-4	229*	229*	188	207	-004**	-7331**	-052**	-008**	-189**	-006**	-034**	011**	-060**	-1096**	189	042**	-044**	-011**	-099**
K1-4C	-037**	-037**	138	1.069	-0040**	-11215**	-020**	-011**	184**	-003**	009**	001*	1.17**	-513**	-928**	-007**	-048**	-012**	-107**
9608U	-087**	-087**	122	157	-0039**	-10098**	-032**	026**	-163**	014**	004**	-003**	-043**	-046**	989	064**	-045**	-011**	-100**
BVC-1	-121**	-12**	-028**	-1.10**	-0039**	-7681**	019**	016**	090**	002**	-016**	-025**	-050**	-363**	-1294**	005**	-021**	-005**	-047**
GUK-1	-171**	-172**	072	090	-0039**	-7015**	014**	0007**	0003	-002**	-009**	029**	014**	-446**	039	016**	-019**	-0047**	-042**
GUK-2	-204**	-204**	072	157	-0039**	-8748**	016**	-021**	-101**	-011**	-003**	031**	104**	137	-044**	027**	-026**	-007**	-057**
GUK-2-1	-204**	-203**	-178**	-077**	-0039**	111.19	-018**	017**	-054**	007**	047**	015**	-006**	-096**	856	-067**	035**	009**	078**
LCA334	-004**	-0039*	-178**	-160**	0127**	17635	-044**	-016**	-103**	-017**	043**	-004**	057**	837	-811**	-059**	040**	010**	088**
LCA960	0627	0627	-178**	-127**	0127**	9235	054**	-0002**	-122**	036**	-057**	-030**	-040**	004	123	-027**	060**	015**	133**
KDC-1-1	-154**	-153**	105	057	-0039**	-5998**	032**	002**	098**	-010**	-007**	002**	017**	537	473	-058**	-010**	-002**	-023**
P. Jwala	-137**	-137**	122	240	-0039**	-4548**	-076**	-022**	-180**	-007**	014**	-025**	-023**	-546**	-1594**	-035**	-042**	-010**	-093**
KA-2	-137**	-137**	-078**	-243**	-0039**	-6465**	1.11**	-0045**	-072**	-010**	-028**	-003**	-026**	-379**	-761**	-032**	017**	004**	038**
K1-4D	-071**	-072**	022	074	-0039**	-5598**	085**	-0088**	253**	014**	-007**	025**	-033**	704	1606	022**	011**	003**	025**
PSBR	279**	279**	-045**	-077**	0127**	12002	-081**	-0010**	-013**	-015**	003**	-009**	-013**	721	-311*	-025**	008**	002**	019**
BVC-37	062	063	138	190	0127**	7802	024**	0252**	1.15**	021**	039**	012**	024**	204	2256*	076**	048**	012**	107**
SED	060	060	3075	084	010	1482	006	0003	006	001	005	008	000	251	210	000	004	001	010
CD 5%	1.19	1.19	6178	168	021	2977	0119	0007	0116	001	010	008	000	505	422	000	2977	002	020
CD1%	159	159	8236	224	028	3969	015	0009	016	002	013	010	000	673	563	000	3969	003	026
Lines																			
JNA1	004	0039	0441	085*	0078**	-1578**	081**	019**	183**	002**	050**	-012**	018**	433	1845**	-016**	029**	007**	064**
ACA1	033*	033*	0147	-027**	-0039**	22598	-060**	-013**	-139**	-002**	-014**	0017**	003**	-19**	-917**	008**	-018**	-005**	-039**
ACA2	-037**	-037**	-059**	-059**	-0034**	-6814**	-020**	-0057**	-045**	0005**	-036**	0106**	-021**	-241**	-928**	008**	-011**	-003**	-024**
SED	025	0250	1292	0351	0043	622	0023	0002	0024	0003	0020	0015	0000	106	082	0000	002	001	004
CD 5%	050	0502	2595	0705	0087	1550	0048	0003	0048	0006	0041	0031	0000	212	178	0000	004	001	008
CD 1%	067	0669	3460	094	0116	1667	064	0004	0065	0008	0054	0042	0000	283	236	0000	005	001	011

*, **Significant at p = and 0.01, respectively.

DFI = Days to first flower initiation, DFF = Days to fifty per cent flowering, DFR = Days to first fruit ripening, DFH = Days to first harvest, NOP = Number of pickings, NFP = Number of fruits plant^{-1}, FFW = Fresh fruit weight fruit^{-1} (g), DFW = Dry fruit weight fruit^{-1} (g), FL = Fruit length (cm), FD = Fruit diameter (cm), PL = Pedicel length (cm), PTL = Petiole length (cm), NPB = Number of primary branches, PH = Plant height (cm), NS = Number of seeds fruit^{-1}, TSW = 1000 seed weight (g), FFWP = Fresh fruit weight plant^{-1} (kg), DFWP = Dry fruit weight plant^{-1} (kg), NPY = Net plot yield (kg).

Among the lines and testers genotypes SKS, PantC-1, GUK2-1, LCA334, LCA960, KA-2, K1-4D, PSBR, BVC-37 and JNA1 were found to be best general combiner for traits fresh fruit weight plant^{-1}, dry fruit weight plant^{-1} and net plot yield. Therefore, these genotypes can be utilized for producing promising hybrids in hybridization programme.

In general, genotype SKS, BVC-37, LCA334 and JNA1 male and female respectively were found to be good general combiner for most of the characters. The traits like primary branches have direct bearing on number of fruits and numbers of fruits have positive impact on yield, hence these four genotypes viz., SKS, BVC-37, LCA334 (male) and JNA1 (female) can be used to produce the best hybrid. JNA1/BVC-37, JNA1/PSBR, JNA1/SKS, JNA1/9608U and JNA1/GUK-2 were the best five crosses each in respect to *per se* performance and significant sca effects (Table 6). Among the five best crosses, highly significant sca effects were recorded by crosses JNA1/BVC-37 and JNA1/PSBR for fresh fruit weight plant^{-1} and dry fruit weight plant^{-1}. It was evident that the cross with high x low gca effect could produce desirable transgressive segregants. JNA1/BVC-37, JNA1/PSBR, JNA1/SKS, JNA1/9608U and JNA1/GUK-2 showed highly significant sca effects with parents having high x low general combiners, it might be attributed to sizeable portion of additive x additive gene action.

Table 6. Estimates of sca effects of crosses for different traits in chilli

Crosses	DFI	DFF	DFR	DFH	NOP	NFP	FFW	DFW	FL	FD	PL	PTL	NPB	PH	NS	SW	FFWP	DFWP	NPY
JNA1/ SKS	022	-245**	-784**	-680**	-063**	368	053**	030**	250**	004**	433	-018**	-075**	1286**	2000**	062**	009	002	261
JNA1/ PantC-1	-395**	-145	-851**	-103**	004**	-6616**	062**	013**	121**	001	333	-005	079**	020	45	-028**	025**	006**	404
JNA1/G-4	005	-028	-001	070	004**	-499	045**	-006**	036**	-007**	263	019**	-058**	153	-533	042**	0003	-0001	186
JNA1/K1-4C	-128	-1.12	082	070	004**	-699	-006	025**	195**	-006**	403	-014*	015**	353	3433**	-025**	-017**	-004**	137
JNA1/9608U	038	-012	-101	-097	004**	301	-1.12**	-009**	-228**	-013**	343	-018**	-025**	-1280**	1.17	-050**	-034**	-008**	1.11
JNA1/BVC-1	055	105	299**	270**	003**	101	005	010**	201**	-009**	303	047**	032**	586**	100	056**	-0075	-002	211
JNA1/GUK-1	105	055	1.16	136	003**	701	-010	003**	-095**	-002	363	-013*	-051**	120	-1133**	084**	-008	-002	212
JNA1/GUK-2	055	072	032	153*	004**	-432	-078**	-043**	-082**	-006**	293	-010	029**	086	700*	-235**	-029**	-007**	158
JNA1/GUK-2-1	272**	338**	216**	286**	003**	-3166	004	028**	233**	-011**	433	009	039**	553**	1150**	100**	001	0004	364
JNA1/LCA334	-045	105	249**	069	004**	-3916	009	-012**	-139**	-009**	403	049**	-045**	-647**	-1183**	010**	010	003*	394
JNA1/LCA960	-045	-012	216**	086	003**	-8082**	051**	003**	-167**	053**	253	-0001	-028**	-347	-717*	042**	-009	-003	386
JNA1/KDC-1-1	0212	122	016	-030	004**	901	045**	003**	-043**	-003**	313	-019**	1.153**	-1014**	1317**	-045**	008	0017	263
JNA1/P. Jwala	022	-062	-268**	-1.14	004**	434	-044**	-024**	-139**	-007**	363	026**	005**	-647**	-1467**	-037**	-016**	-004**	151
JNA1/KA-2	138	055	566**	569**	003*	968	-011	-011**	051**	003**	353	0004	049**	-880**	-2800**	020**	-0074	-002	273
JNA1/K1-4D	138	072	283**	269**	003*	368	-008	-012**	-034**	-001	363	037**	-035**	520**	-1217**	057**	-007	-002	290
JNA1/PSBR	055	105	1.16	186*	003*	14601**	-037**	-008**	-130**	003*	333	-052**	-055**	153	-950**	025**	038**	009**	380
JNA1/BVC-37	-312**	-412**	-184*	-214**	004*	4667*	030**	009**	-030**	0116**	433	-038**	009**	986**	733*	-079**	043**	011**	477
ACA1/SKS	-0256	-087	395**	493**	031**	-285	-071**	-006**	-181**	-0022*	213	-040**	041**	-343	-421	036**	-016**	-004**	1.17
ACA1/PantC-1	358**	-036	478**	593**	-002**	5331*	-021*	-018**	-169**	0008	323	-034**	-026**	-1.10	-1121**	-042**	-007	-002	245
ACA1/G-4/	008	030	078	-107	-002**	-152	-0004	006**	074**	005**	283	006	007**	623**	1196**	-041**	006	001	108
ACA1/K1-4C	025	047	-038	043	-002**	848	014	-018**	-191**	-025**	213	018**	-069**	-176	-2637**	042**	015**	004*	1.17
ACA1/9608U	-059	-053	028	077	-002**	-752	050**	-0095**	069**	0102**	323	011	-109**	1290*	-3054**	120**	016**	004**	132
ACA1/BVC-1	-092	-036	-322**	-357**	-002**	-552	-003	022**	-009**	0102**	303	-010	-003**	060	679*	0592**	004	001	148
ACA1/GUK-1	-092	-086	-405**	-340**	-002**	-952	007	-002**	039**	-004**	323	-019**	-016**	-7.10**	296	-058**	005	001	152
ACA1/GUK-2	-092	-120	-038	-1.73*	-002**	-085	-002	003**	070**	-008**	303	-011	-1.16**	-943**	2079**	1.73**	006	002	147
ACA1/GUK-2-1	025	-003	-655**	-640**	-002**	1181	-004	-019**	-041**	017**	323	-043**	-126**	-476*	-21.71**	-029**	-006	-002	258
ACA1/LCA334	008	1.14	378**	393**	-002**	4331 *	-026*	004**	045**	0032**	333	-019**	201**	823**	346	-024**	-018**	-005**	241
ACA1/LCA960	158*	347**	095	210**	-002**	5564**	-03**	002**	066**	-026**	245	018**	067**	024	263	-029**	004	001	325
ACA1/KDC-1-1	-026	080	145	243**	-002**	-1552	-029**	009**	-005**	0015	295	008	-039**	660**	1196**	-092**	-007	-001	141
ACA1/P. Jwala	-026	-003	162*	010	-002**	-219	027**	004**	101**	0012	335	001	061*	524**	1413**	-055**	011	003	12
ACA1/KA-2	-059	-086	-605**	-657**	-002**	-1286	018	002**	031**	-0025*	275	032**	004**	290	879**	019**	006	001	213
ACA1/K1-4D	-059	-070	1618*	193**	-002**	-1285	-002	004**	-008**	0035**	305	017*	021**	-7.10**	713*	-035**	-001	-0003	213
ACA1/PSBR	-092	-086	045	-090	-002**	-7402**	021*	003**	074**	004**	295	036**	051**	-177	180	-020**	-020**	-005**	163
ACA1/BVC-37	041	047	095	1.10	-002**	-2735	052**	014**	036**	0112**	325	029**	054**	-6431**	163	-022**	005	001	305

*, **Significant at p = 0.05 and 0.01, respectively.

Table 6. (contd.)

Crosses	DFI	DFF	DFR	DFH	NOP	NFP	FFW	DFW	FL	FD	PL	PTL	NPB	PH	NS	SW	FFWP	DFWP	NPY
ACA2/SKS	0.04	3.31**	3.89**	1.87*	0.31**	-0.82	0.18	-0.24**	-0.69**	-0.02	2.25	0.57**	0.34**	-9.43**	-15.80**	-0.97**	0.07	0.017	1.90
ACA2/PantC-1	0.37	1.81*	3.73**	4.37**	-0.02**	12.83	-0.42**	0.05**	0.49**	-0.02	3.15	0.39**	-0.53**	0.90	6.71*	0.69**	-0.18**	-0.05**	2.43
ACA2/G-4	-0.13	-0.02	-0.78	0.37	-0.02**	6.51	-0.44**	-0.002	-1.10**	0.03*	2.65	-0.25**	0.51**	-7.76**	-6.63*	-0.01**	-0.06	-0.01	1.04
ACA2/K1-4C	1.04	0.65	-0.44	-1.13	-0.02**	-1.49	-0.08	-0.07**	-0.04*	0.31**	3.25	-0.04	0.54**	-1.77	-7.96**	-0.16**	0.02	0.00	1.11
ACA2/9608U	0.21	0.65	0.73	0.21	-0.02**	4.51	0.62**	0.19**	1.59**	0.03**	2.65	0.08	1.34**	-0.10	29.37**	-0.70**	0.18**	0.04**	1.59
ACA2/BVC-1	0.37	-0.69	0.23	0.87	-0.02**	4.51	-0.02	-0.31**	-1.93**	-0.01	2.65	-0.37**	-0.29**	-6.43**	-7.79**	-1.16**	0.04	0.01	1.69
ACA2/GUK-1	-0.13	0.31	2.89**	2.04**	-0.02**	2.51	0.03	-0.007	0.56**	0.06**	2.05	0.32**	0.68**	5.90**	8.37**	-0.26**	0.03	0.01	1.72
ACA2/GUK-2	0.37	0.48	0.06	0.21	-0.02**	5.18	0.80**	0.40**	0.12**	0.14**	3.15	0.21**	0.87**	8.57**	-27.79**	0.63**	0.24**	0.06**	2.12
ACA2/GUK-2-1	-2.96**	-3.35**	4.39**	3.54**	-0.02**	19.84	-0.001	-0.09**	-1.93**	-0.05**	3.05	0.35**	0.87**	-0.77	10.21**	-0.71**	0.05	0.01	3.07
ACA2//LCA334	0.37	-2.19*	-6.27**	-4.63**	-0.02**	-4.16	0.17	0.08**	0.95**	0.06**	3.25	-0.29**	-1.56**	-1.77	8.37**	0.14**	0.08	0.02	3.22
ACA2//LCA960	-1.13	-3.35**	-3.11**	-2.96**	-0.02**	25.18	-0.20	-0.057**	1.01**	-0.27**	2.65	-0.18**	-0.39**	3.24	4.54	-0.14**	0.06	0.02	3.54
ACA2/KDC-1-1	0.04	-2.02*	-1.61*	-2.13**	-0.02**	6.51	-0.16	-0.12**	0.48**	0.02	3.05	0.11	-0.76**	3.57	-25.13**	1.37**	-0.003	0.00	1.79
ACA2/P. Jwala	0.04	0.65	1.06	1.04	-0.02**	-2.16	0.16	0.20**	0.38**	0.06**	2.75	-0.27**	-0.66**	1.24	0.54	0.93**	0.05	0.02	1.32
ACA2/KA-2	-0.79	0.31	0.39	0.87	-0.02**	3.18	-0.07	0.09**	-0.82**	-0.004	2.15	-0.33**	-0.53**	5.90**	19.21**	-0.39**	0.01	0.002	2.27
ACA2/K1-4D	-0.79	-0.02	-4.44**	-4.63**	-0.02**	9.18	0.10	0.08**	0.43**	-0.024*	2.35	-0.55**	0.14**	1.90	5.04	-0.22**	0.08	0.02	2.59
ACA2/PSBR	0.37	-0.19	-1.61*	-0.96	-0.02**	-71.99**	0.15	0.06**	0.57**	-0.07**	3.05	0.16*	0.04**	0.24	7.71**	-0.05**	-0.18**	-0.05**	1.89
ACA2/BVC-37	2.7**	3.65**	0.89	1.04	-0.02**	-19.32	-0.82**	-0.23**	-0.06**	-0.23**	2.85	0.08	-0.63**	-3.43	-8.96**	1.00**	-0.47**	-0.12**	2.10
SED	0.76	0.90	0.75	0.71	0.00	20.10	0.10	0.004	0.02	0.01	0.05	0.06	0.00	1.90	2.77	0.00	0.06	0.01	0.12
CD 5%	1.53	1.80	1.50	1.42	0.00	40.37	0.20	0.01	0.03	0.02	0.09	0.13	0.00	3.81	5.56	0.00	0.11	0.03	0.25
CD 1%	2.04	2.40	2.00	1.90	0.00	53.82	0.26	0.01	0.05	0.03	0.12	0.17	0.00	5.08	7.41	0.00	0.15	0.04	0.33

*, **Significant at p = 0.05 and 0.01, respectively.

DFI = Days to first flower initiation, DFF = Days to fifty per cent flowering, DFR = Days to first fruit ripening, DFH = Days to first harvest, NOP = Number of pickings, NFP = Number of fruits plant^{-1}, FFW = Fresh fruit weight fruit^{-1} (g), DFW = Dry fruit weight fruit^{-1} (g), FL = Fruit length (cm), FD = Fruit diameter (cm), PL = Pedicel length (cm), PTL = Petiole length (cm), NPB = Number of primary branches, PH = Plant height (cm), NS = Number of seeds fruit^{-1}, TSW = 1000 seed weight (g), FFWP = Fresh fruit weight plant^{-1} (kg), DFWP = Dry fruit weight plant^{-1} (kg), NPY = Net plot yield (kg).

4. Conclusion

It has been concluded that the magnitude of heterobeltiosis was high (20% >) with majority of the crosses for most of the traits. Hence, heterosis breeding is favoured as suggested by Patel et al., (2001) in chilli. JNA1/BVC-37 (48.47%), JNA1/PantC1 (25.76%) and JNA1/LCA334 (25.33%) recorded more than 25% heterosis over best standard check of non male sterility based hybrid. However, F1 hybrids, JNA1/PanC1 (152.63%), JNA1/LCA334 (370.49%) and JNA1/PSBR (185.71%) registered more than 150% heterobeltiosis, while, three newly developed CMS based hybrids viz., JNA1/LCA960 (69.05%), JNA1/GUK2-1 (50.85%) and ACA2/LCA960 (57.17%) were able to yield more than 50% heterobeltiosis. Therefore, efforts should be concentrated for the development of male sterility based hybrids using cytoplasmic male sterile lines to minimize the cost of F_1 seeds and quality seed production in chilli. Cross JNA1/BVC-37 gave the highest yield along with highly significant sca effects thus proved as potential hybrids and could be considered for commercial exploitation of hybrid vigour in chilli (*Capsicum annuum* L.) after confirmation with multilocational testing.

References

Allard, R.W. (1960). Principles of Plant Breeding Ist Edn. London, John Wiley and Sons, Inc.

Dash, S. S., Kumar, S., & Singh, J. N. (2001). Cytomorphological characterization of a nuclear male sterile line of chilli pepper (*Capsicum annuum* L.). *Cytologia*, *66*(4), 365-371. http://dx.doi.org/10.1508/cytologia.66.365

Fonseca, S., & Patterson, F. L. (1968). Hybrid vigour in a seven parent diallel cross in common wheat (*Triticum aestivum* L.). *Crop Science*, *8*, 85-88. http://dx.doi.org/10.2135/cropsci1968.0011183X000800010025x

Joshi, S., Thakur, P. C., & Verma, T. S. (1995). Hybrid vigour in bed shaped paparika (*Capsicum annuum* L). *Vegetable Science*, *22*(2), 105-108.

Kempthorne, O. (1957). An introduction to genetic statistics, New York, John Willey and Sons. pp. 486-211.

Kim, D. H., & Kim, B. D. (2005). Development of SCAR markers for early identification of cytoplasmic male sterility genotype in chilli pepper (*Capsicum annuum L.*). *Molecular Cells*, *20*, 416-422.

Kumar, S., Singh, V., Singh, M., Rai, S. K., Kumar S., & Rai, M. (2007). Genetics and distribution of fertility restoration associated RAPD markers in pepper (*Capsicum annuum L.*). *Scientia Horticulturae*, *111*, 197-202. http://dx.doi.org/10.1016/j.scienta.2006.10.021

Lee, J., Yoon, J. B., & Park, H. G. (2008a). A CAPS Marker associated with the partial restoration of cytoplasmic male sterility in chilli pepper (*Capsicum annuum* L). *Molecular Breeding*, *21*, 95-104. http://dx.doi.org/10.1007/s11032-007-9111-0

Lee, J., Yoon, J. B., & Park, H. G. (2008b). Linkage analysis between the partial restoration (*pr*) and the restorer of fertility (*Rf*) loci in pepper cytoplasmic male sterility. *Theory and Applied Genet*ics, *7*, 383-389. http://dx.doi.org/10.1007/s00122-008-0782-7

Parvez, S. (2006). Recent advances in understanding genetic basis of heterosis in rice (*Oriza sativa* L.). *Revista UDO Agricola*, *6*(1), 1-10.

Patel, J. A., Shukla M. R., Doshi K. M., Patel S. B., & Patel, S. A. (1997). Hybrid vigour of quantitative traits in chilli (*Capsicum annuum* L.). *Vegetable Sci*ence, *24*(2), 107-110.

Patel, J. A., Patel, M. J., Patel, A. D., Acharya, R. R., & Bhalala, M. K. (2001). Hybrid vigour of quantitative traits in chilli (*Capsicum annuum* L.). *Vegetable Science*, *28*(2), 130-132.

Shifriss, C. (1997). Male sterility in pepper (*Capsicum annuum* L.). *Euphytica*, *93*, 83-88. http://dx.doi.org/10.1023/A:1002947907046

Turner, J. H. (1953). A study of heterosis in upland cotton, combining ability and inbreeding effects. *Agronomy Journal*, *45*, 487-490. http://dx.doi.org/10.2134/agronj1953.00021962004500100008x

Wang, L. H., Zhang, B. X., Lefebvre, V., Huang, S. W., Daubeze, A. M., & Palloix, A. (2004). QTL analysis of fertility restoration in cytoplasmic male sterile pepper. *Theory and Applied Genet*ics, *109*, 1058-1063. http://dx.doi.org/10.1007/s00122-004-1715-8

Zhang, B. X., Huang, S. W., Yang, G. M., & Guo, J. Z. (2000). Two RAPD markers linked to a major fertility restorer gene in pepper. *Euphytica*, *113*, 155-161. http://dx.doi.org/10.1023/A:1003945723196